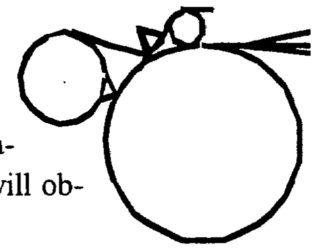
FERMILAB-TM-1806

Investigation 11: Seeing Tracks in Clouds



Purpose:
One of the earliest ways physicists were able to see tracks from subatomic particles was with the cloud chamber. In this activity, students will observe the tracks of subatomic particles as the tracks are created.

Objectives:
Using a cloud chamber, students will observe the fresh tracks of subatomic particles emitted by a radioactive source.
Students will attempt to observe two different types of particle tracks and compare these to photos of bubble chamber tracks.
Students will experience the excitement of observing first-hand the indirect evidence of subatomic particle events as they happen.

Materials:
1 cloud chamber
1 particle source
1 pint 90% isopropanol (rubbing alcohol [school supply])
Dry ice (purchase from local ice cream shop or other source and store in thick Styrofoam cooler)
Intense beam light source (small krypton bulb flashlights, projectors, desk lamps, etc. from school supply)
Paper or plastic dish or tray with vermiculite (to hold and insulate dry ice [school supply])
1 set of bubble chamber photos
Eyedroppers or dropper bottles
Hammer and chisel to break dry ice
Gloves
Student Investigation Sheets - "Seeing Tracks in Clouds"

> *Note: Radioactive elements continually undergo a process of radioactive decay during which their nuclei emit high-speed particles and photons that are too small to be seen under a microscope. The cloud chamber is an instrument designed for the study of the trails, or tracks, of these radioactive emissions.*
> *Cloud chambers work as follows: The air in the cloud chamber <u>must</u> be saturated with alcohol vapor. In this investigation, that is accomplished by soaking the felt in the chamber. When the high-energy particles plow through the air, electrons are knocked loose from some of the molecules and form ions. Ions act as excellent centers for condensation. This condensation, however, must be stimulated by cooling the air. In this investigation, the dry ice cools the air. The alcohol vapor condenses on the ions in the cool air, leaving a droplet trail that clearly reveals the path of the particles.*
> *Three types of radiation may be emitted by a radioactive element. These are α-particles (alpha-particles), which consist of two protons and two neutrons; β-particles (beta-parti-*

cles), high-speed electrons; and γ-ray (gamma-ray) photons, electromagnetic packets of energy similar to x-rays and light.

When observing the cloud chamber, one can tell the difference between the tracks left by the different types of particles. α-particle tracks are thick and heavy, while β-particle tracks are thinner and much more difficult to see, requiring an intense light source, such as a high-power flashlight or the light beam from a slide projector. α-particles travel more slowly than β-particles, although the difference is difficult to see with the naked eye. The reason for these differences is the difference in mass of the particles: α-particles are about 8,000 times more massive than β-particles, so they travel more slowly and leave a thicker trail. γ-rays will not be visible since they are uncharged and therefore do not interact readily with charged particles to form ions.

Use care and observe all safety precautions when handling the dry ice. Wear gloves and do not allow students to touch the dry ice. One suggestion is to place small chunks of dry ice in a small box or tray partially filled with vermiculite. This will allow students to move the dry ice safely as well as slow down its sublimation rate.

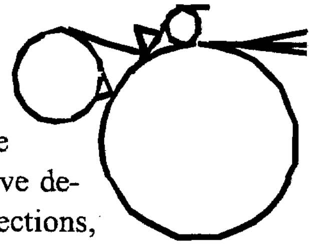
If you are using the cloud chambers for more than one class you should make sure that the chambers are removed from the dry ice and left open between classes. <u>This is very important, as it is necessary for the cloud chambers to dry out in order to work effectively for the next class</u>.

Procedure:

1. Divide the class into one team per cloud chamber.
2. Discuss the background information on cloud chamber function, particles and set-up. (See Teacher Notes.)
3. Provide the student teams with cloud chambers and trays with the dry ice in vermiculite.
4. Model the following procedure for the class:
   A. Saturate the felt (blotter) band on the inside of the cloud chamber with alcohol.
   B. Place the particle source on the bottom center of the chamber and replace the cover.
   C. Place the cloud chamber on the surface of the dry ice. (The dry ice should be placed on a paper plate or a piece of aluminum foil or in vermiculite in a small box.)
   D. Wait for the appearance of clouds.
   Note: The alcohol will evaporate into the air within the chamber forming a gas cloud. As it descends toward the bottom of the chilled chamber, the alcohol reaches a supersaturated condition in which tracks left by the particles are visible in a strong light. It will take a minute or two for the chamber to cool sufficiently for proper operations after it has been placed on the dry ice. Viewing will be much better if the room lights are turned off.
5. View the particle tracks by shining a strong light through the side of the chamber, or from above, onto the black surface of the chamber. (Try both approaches and choose the best effect.) Any strong beam will work as a light source. A powerful flashlight or a projector will work best.

6. Show bubble chamber photographs after the students have completed the cloud chamber portion of the investigation. If time allows, identify and discuss tracks of different types of particles.

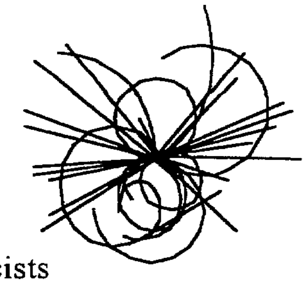
Supplemental Investigation 11A: Counting Particles



To extend the previous investigation, have the students use their problem-solving abilities to design a method for counting and classifying the observed particles. One approach the students could take might involve devising a method of visually cutting the circle of the chamber into sections, counting what is happening in their particular section for a period of time, and multiplying by the number of sections.

Also, devices such as a wooden splint, broken into four places and placed on edge around the radioactive sample will help separate the α-particles from the β-particles. The β-particles are small and fast enough to shoot through the wood, but the wood traps the slower, heavier α-particles. A strong rare earth magnet (such as the Mega-Magnet available from Flinn Scientific) may be used to bend the path of the particles.

Student Sheet Investigation 11: Seeing Tracks in Clouds



Name______________________
Date_______________________

Purpose:
The cloud chamber experiment was an early method by which physicists could see and photograph the tracks of subatomic particles. In this investigation, you will observe tracks of subatomic particles as these particles are created by a radioactive source, just as physicists did.

Procedure:
1. Set up your cloud chamber as directed by the teacher. Do not touch the dry ice. Dry ice will cause severe skin damage if touched without proper precautions and protection.
2. Carefully observe the tracks of the invisible particles in the cloud chamber.
3. Can you distinguish between different types of tracks? Describe the different types of tracks you see.
4. Examine the bubble chamber photographs. What do you observe about these tracks? How do they compare to the tracks in your cloud chamber?
5. What is the purpose of the dry ice?

6. Why is there a black bottom on the cloud chamber?

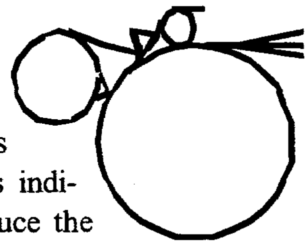
7. What do the differences in the types of tracks you observed (see #3) indicate about the types of particles that created them? Explain your ideas.

8. The tracks you're seeing are made by two different types of particles: α-particles (alpha-particles) and β-particles (beta-particles). An α-particle is made of two protons and two neutrons. A β-particle is a single electron. Which type of particle do you think makes a heavier track, α or β? Why?

9. Which type of particle do you think travels more quickly, α or β? Why?

10. Why is seeing the tracks of invisible particles useful? Why would it be especially useful to scientists at Fermilab?

Investigation 12: Soda Bubble Tracks Teacher Demo



Purpose:

Inspiration may come from the strangest places! A group of physicists were informally discussing how they might be able to observe particles indirectly. When one individual shook some salt into his beverage to reduce the carbonation, all eyes went to the trail of bubbles that formed as the salt sank to the bottom of the glass. From that event, the first bubble chamber detector was born. In this investigation, students will observe the particle trails created in this historical event, which was an inspiration to the future of particle physics.

Objective:

Students will observe the particle trails created by salt particles falling through a carbonated beverage.

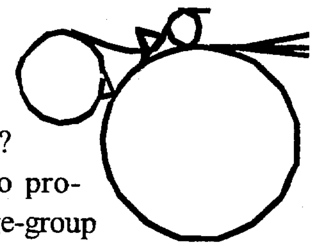
Materials:

Salt
Clear carbonated beverage
Clear cup

Procedure:

1. Fill a transparent glass with a clear beverage, such as club soda, 7UP, or sparkling water. Let the cup settle until no carbonation bubbles are rising to the surface.
2. Gather the class around your demonstration table, then slowly drop a few grains of salt into the cup. (Alternatively, you can place the cup on the overhead and have students watch the screen as the demonstration is projected.)
3. Have the students carefully observe what happens as the salt crystals sink to the bottom.
4. To facilitate discussion, you may want to pose the following questions:
   - How do we know where the salt crystals went?
   - What may have caused the bubbles to form?
   - What are some other examples of "trails" such as the bubbles that mark where something has been?
   - Using the bubbles, what could we learn about the salt or the liquid? What could we measure?
5. You may want to conclude this discussion with the story of how this actually inspired the creation of the first bubble chamber detectors, and show the photos of bubble chamber experiments.

Investigation 13: Breaking through Walls Group Project



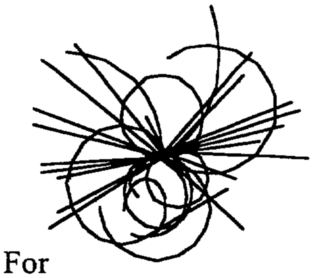
Purpose:
Why do we build such huge machines to look at such tiny parts of nature? It is important for students to know that large machines are necessary to provide the energy necessary to break nature into smaller pieces. This large-group activity will help students understand this idea.

Objective:
By constructing an accelerator and a target to explore, students will determine that "bigger is better" is often true when it comes to designing accelerated probes.

Materials:
100 dominoes per each pair of teams
1 "Hot Wheels" or similar car per each pair of teams
Several pieces of Hot Wheels ramp
Several books
"Treasure"—a pile of candy, a secret written on a piece of paper, or anything of value
Student Investigation Sheet - "Breaking through Walls"

Procedure:
1. Break the class into an even number of teams and then pair the teams up. In each pair of teams:
    - One team is to build a "fort" consisting of the dominoes arranged in whatever way they think will best keep the "treasure" safe from the car.
    - The other team will construct a ramp of car tracks and books to allow for the car to travel down and "discover" the "treasure."
2. Both teams should record in their journals their efforts to design a better "fort" or ramp.
3. As the students work at these two tasks, look for opportunities to point out that no matter how cleverly the fort is built, a more energetic car will always be able to break down the walls.
4. After the "fort" is built, have the students building the ramp launch the car toward the fort in an effort to break through to the "treasure."
5. Next, have the teams switch roles and repeat the investigation. Encourage them to record in their journals their observations on the first attempt and what they are doing to improve on the other team's efforts.
6. After the second attempt, discuss the observations students make as well as answers to questions from the student sheet.

Student Sheet Investigation 13: Breaking Through Walls



Name___________________________
Date_____________________________

Purpose:
Scientists often explore tiny objects by sending probes inside the object. For example, you probably have seen pictures of the insides of your teeth when you visited the dentist. Your dentist took these pictures by sending x-rays into your teeth. Today you will try to see how machines can help you explore the insides of an object.

Procedure:
1. Each of you will be on a team that will be competing against one other team.
2. Team 1 will have a "treasure" and dominoes to protect it. Arrange the dominoes to make a "fort" protecting the treasure.
3. Team 2 will have several pieces of car track and a car that they will launch at the fort. Their objective is to make their way to the treasure. The car may only be launched by sending it down the ramp.
4. The car may be launched only as many times as your teacher permits. How would you suggest that the ramp be set up so that the treasure will be reached using the fewest launches of the car?
5. Draw the fort and ramp set-up in the space below.

6. Was the car able to reach the treasure?_______

7. How many launches were needed?_______
8. Now switch places. Team 2 will build the fort, and Team 1 will build the ramp and try to break through.
9. Draw the new fort and ramp set-up in the space below.

10. Was the car able to reach the treasure?_______

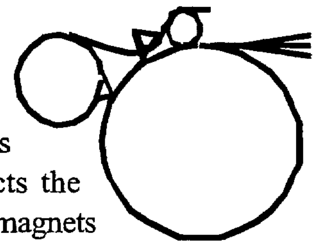
11. How many launches were needed?_______
12. Based on your experience, what would you do to make the fort the strongest it can be?

13. Based on your experience, how would you build your ramp to give yourself the best chance of reaching the treasure on the first try?

14. What "treasures" do Fermilab scientists try to discover?

15. How does this investigation resemble their search?

Investigation 14: Using Motion to Find What You Can't See



Purpose:

The key probes used by particle physicists to investigate small objects are high-energy particles. Often, the magnetic field of the target deflects the particle probe. In this section, students will use metal balls and hidden magnets to experience one way that physicists use particle probes to locate and describe unseen objects.

Objectives:

Using a moving probe, students will attempt to find a magnet taped to the underside of a mystery box.

Students will model the way physicists use particle probes to determine the properties of unseen objects.

Students will experience a situation analogous to that of particle physicists—a situation in which the objects they are investigating are really untouchable and very difficult to locate and identify using indirect methods.

Materials (for each team):

1 prepared mystery box (See *Note.*)
1 ramp (ruler) and stand (block with groove)
5 steel ball bearings, various sizes
1 catcher (Box lids or carpet remnants work well.)
Grid paper copies
1 ruler
Student Investigation Sheets - "Using Motion to Find What You Can't See"

Note: In a previous investigation, students utilized their senses and hand-held probes to gather indirect evidence about the contents of a mystery box. Physicists, however, cannot use manual probes nor physically handle an atom. The identification of the parts of an atom must be accomplished by using high-energy particle probes that are not touched.

The physicists use smaller and more energetic probes as "bullets" to obtain increasingly accurate data about the inside of the atom.

This investigation is a simulation of a particle probe traveling at various speeds towards its target. Just like Fermilab scientists, students will see complete misses of the target. Use this to emphasize the idea that matter and atoms are mostly empty space. When a probe nears the target a deflection of the probe's path may occur. With each deflection, students will know more about the position of the target. Smaller and smaller probes will help distinguish the shape of the hidden object.

At Fermilab, when a particle is given more energy, it behaves like a smaller probe will in this investigation. So, the smaller the object focus of the investigation, the more energy is needed to "see" it.

There are several similarities and differences between this investigation's steel ball bearings and the protons used at Fermilab. Proton probes have a positive electrical charge *and are repelled by the positive charge of an atomic nucleus or other protons. Deflection of the proton probe is usually a push away from another positively charged object. Steel ball-bearing probes have no electrical charge but are attracted toward magnets due to their iron content. Deflection of the steel ball bearing in this investigation is due to a pull* <u>*toward*</u> *the magnet.*

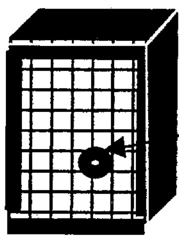
Most protons in the Fermilab accelerator beam pass by target particles or are deflected in a way similar to the metal ball and magnet. The chief difference is that the proton is repelled, while the steel ball bearing is always <u>*attracted*</u>*.*

The proton collision "events" of greatest interest to Fermilab physicists are ones in which the proton probe and the target object form new particles. An analogy with the metal ball and magnet would be a head-on collision out of which little magnets and metal balls flew including some new metal ball magnets that no one had ever seen. Such an "event" might tell us something new about the makeup of magnets and metal balls.

Even though the probe and target in this investigation will not create new particles, we can observe the before-and-after motion of the metal ball probe. This is essentially what physicists do in analyzing particle events at Fermilab: they analyze the mass, speed, and angle of deflection of particles before and after collisions. From this information scientists can learn what particles were deflected or what new particles were created.

Procedure:

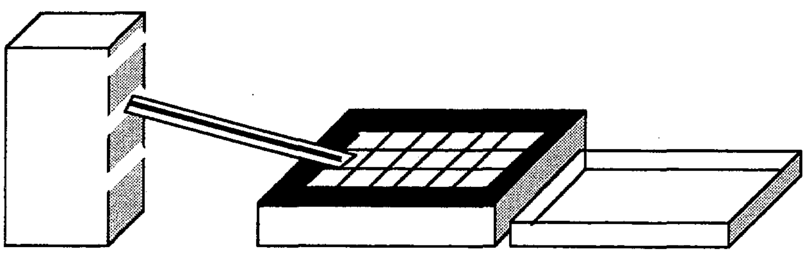
1. To prepare for this investigation, tape a circular magnet to the inside of the box, under the surface grid, so that students cannot see it. If desired, seal the box with masking tape. Place the magnet in a different location in each box.



Tape magnet on underside of box lid.

2. Divide the class into teams of four. and pass out the equipment. Demonstrate the setup of the ramp block and ramp. (See diagram.) Show the students how to catch the probes (ball bearings) in the separate catcher lid for safety and convenience.

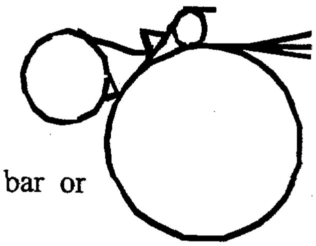
Mystery Box



Catcher Lid

3. Discuss how students will record data on their grid paper.
4. Have the teams collect data by launching the ball and record it on the grid paper.
5. Have students share their results and the answers to the questions on their sheet in a class discussion. Emphasize everyday situations in which people investigate things they can't see, and analogies between this investigation and the work of Fermilab. (e.g., Fermilab scientists are constantly "launching" protons at things they can't see in order to find out more about them.)

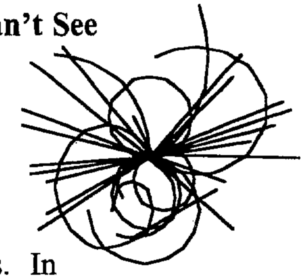
Supplemental Investigation 14A: More Hidden Magnets



There are many possibilities for modification of this investigation that would provide students with an additional challenge:

1. Set up mystery boxes using a variety of types of magnets (e.g., bar or horseshoe).
2. Change other variables, possibly including the size, strength, shape, or quantity of magnets in the box.
3. Use different sizes of steel ball bearings.
4. Change the height of the ramp. (Raising it makes the investigation more challenging, while lowering it makes the investigation easier.)

Student Sheet Investigation 14: Using Motion to Find What You Can't See



Name____________________

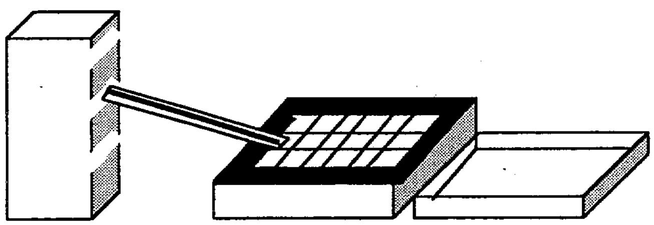
Date____________________

Purpose:

By studying the motion of objects, scientists can learn about unseen events. In this investigation, you will model the way physicists use particle probes to locate and identify unseen objects.

Procedure:

1. Your team's job is to identify the shape, size and location of a mystery object attached to the inside of your mystery box underneath the grid by rolling steel ball bearings down a ramp and over the box.
2. Your team must follow these rules:
   - You cannot open the box.
   - The front edge of the ramp (ruler) must always be in the thick, black border of the grid.
   - Always release the ball-bearing probes from the <u>top</u> of the ramp.
   - Do not place ball-bearing probes directly on the top of the box.
3. Determine which ball-bearing probe will provide you with the best data.
   a) Set up your equipment as demonstrated by your teacher, using the following diagram.



   b) Your group will roll each ball-bearing probe down the ramp (from the top!) at three locations along the short side of the box. Observe the ball-bearing probe closely as it rolls across the box.

   c) After observing each of the ball-bearing probes, select **one** which you will use to determine the exact location and shape of the fixed object or objects in your mystery box.

Ball Probe Selection

We selected the: small medium large extra-large

ball-bearing probe because . . .

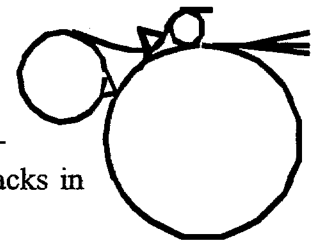
4. Place the ramp in the top slot of the ramp block and position the front edge of the ramp on the black border of the grid system in front of a row of boxes.
5. Label the four sides of the grid system on top of the box A, B, C, and D.
6. Transfer these letters to your copy of the grid.
7. Use your selected ball-bearing probe to systematically search for the object.
   a) Start by lining up the ramp with a row of boxes on the grid and rolling the ball-bearing probe down (from the top of the ramp!).
   b) Observe the ball-bearing probe closely as it rolls across the grid.
   c) On your grid paper, sketch a line that shows how your ball-bearing probe traveled across the grid.
   d) Move the ramp to the next row of boxes and repeat.
8. After finishing step 7, you will have run 26 trials; eight on each long side and five on each short side. You might not know exactly where or what shape the object is yet, but you should have a good idea of what part of the box you want to continue investigating.
9. Continue releasing your ball-bearing probe and sketching its trails. You can release the ball-bearing probe from any location on the perimeter of the box (remember that the end of the ramp needs to be within the black border and you must release the ball-bearing probe from the top of the ramp) as often as necessary. If you run enough trials you should develop an excellent idea of the size, shape and location of the object. Use small spacing between trials. You might try to run trials at different angles. Remember to keep end of the ramp on the black border for every trial.
10. How do you explain curved trails?

11. How do you explain straight trails?

12. What effects do you think changing the ramp height would have on your results?

13. What area(s) of the box did you choose to focus on in Step 9? Why?

14. Explain how this investigation relates to the work physicists do at Fermilab.



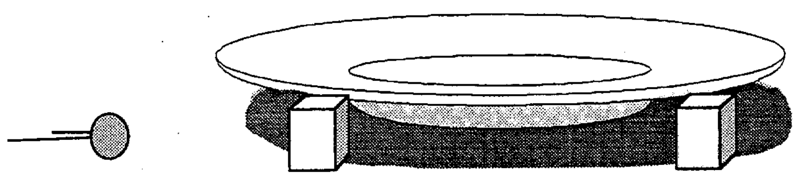
Investigation 15: Magnet Trails

Purpose:
This investigation will allow students to develop their indirect measurement skills. It will also help students understand how particles leave tracks in detectors.

Objective:
Students will explore a method of indirect observation.

Materials:
Each lab group should get the following:
1 plastic dinner plate
4 magnetic marbles
1 ring magnet
1 film canister filled with iron filings
2 marbles
2 large washers
3 or 4 small blocks of wood or spools

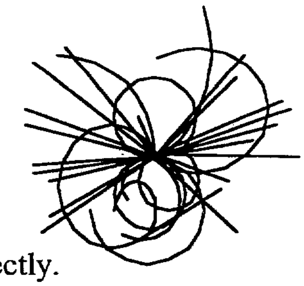
Procedure:
1. Discuss with students how people learn about their world. In the discussion, incorporate examples of how all our senses help us understand our world.
2. Ask how a person can extend the use of the five senses. Examples might include glasses, hearing aids, televisions, or computers.
3. Discuss the process scientists use to construct a model of some unseen part of nature as they learn about the object through experimentation. One common example is the understanding students have about their own body and the organs within it despite the fact that they have never seen their own internal organs. For example, we can infer the existence of the heart without actually seeing it.
4. Divide the class into teams of twos.
5. Give each team the equipment listed above and ask them to set up the plate on the blocks or spools as shown below.



6. Have the students sprinkle iron filings onto the plate from a height of about 20 cm so that a fine, even layer is created.

7. Ask each team to experiment with rolling the magnetic marbles and other items under the plate to see how the filings react. The patterns students create in the filings will be useful to infer how things travel and collide under the plate.
8. Students now can set up experiments for each other. One student turns her back while her partner arranges magnets, washers or marbles under the plate. After he is finished, she may turn around and begin rolling marbles under the plate to try to discover what her partner placed under the plate.
9. Have the student who sets up the materials under the plate draw the arrangement, and have the other student make a drawing of what she believes is under the plate as she investigates it by rolling marbles.
10. As the students experiment and make observations, move around the class and help them form clear inferences (right or wrong) about the experimental set-up.
11. After the investigation, have the class discuss the results. Be sure to ask if their inferences became more or less accurate as they rolled more marbles.
12. Have your students discuss how this investigation is similar or different from experiments at Fermilab. Some questions to discuss with them might be:
    - What do Fermilab scientists use as probes instead of marbles? (Protons.)
    - What are Fermilab targets? (Various. In the collider detectors, they are antiprotons, but in other experiments they can be many other things. They are often some type of metal.)
    - What are Fermilab detectors? (Again, many answers are possible. There are two main types: thin wires that get an electrical charge when charged particles go past them, and scintillating materials that emit light when charged particles travel through them.)

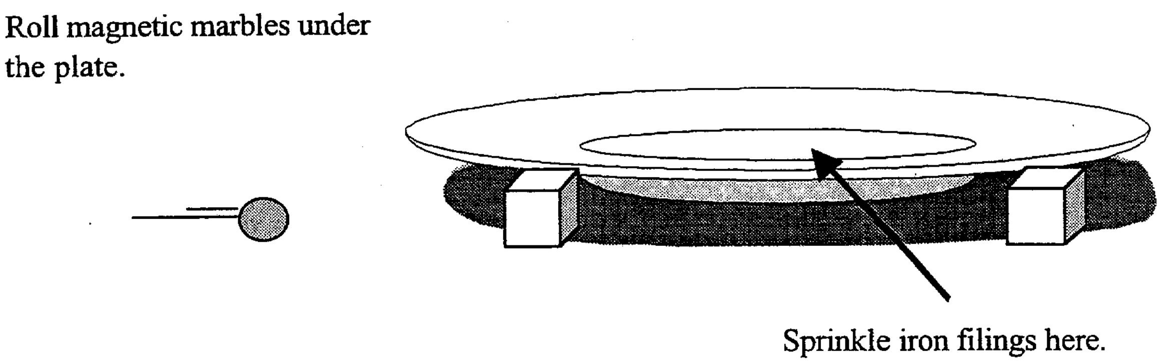
Student Sheet Investigation 15: Magnet Trails



Name________________________
Date________________________

Purpose:
Scientists are often asked to understand things that they cannot see directly.
The purpose of this investigation is to let you predict properties of unseen objects.

Procedure, Part A:
1. After your teacher has given you equipment, set up the experiment with the plastic plate resting on wooden blocks or spools.
2. Sprinkle iron filings in an even layer on the plate. It is best to sprinkle the filings from about 20 cm above the plate. Roll a magnetic marble under the plate as shown below.



3. Watch the iron filings as the magnetic marble rolls under the plate. Record your observations after the questions below.

Questions:
1. Describe and draw what you see when a magnetic marble rolls under the plate.

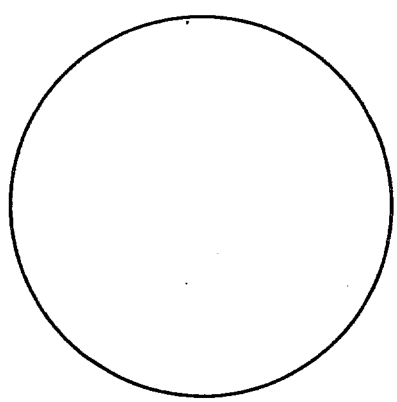
2. Describe what you see when you roll a regular marble under the plate.

3. What do the iron filings look like when you place a ring magnet under the plate?

4. What do the iron filings look like when you place a steel washer under the plate?

Procedure, Part B:

1. Ask your partner to arrange some combination of donut magnet, steel washer, magnetic marbles and regular marbles under the plate while you look away. Your partner does not have to use all of the materials mentioned. (It is often better to use fewer objects.) When your partner is finished, try to determine what is there and how it is arranged by rolling magnetic marbles under the plate. You get six rolls, so think about how you want to use them. Do not look under the plate. Use the patterns produced in the iron filings to answer these questions.
2. Draw a picture in the space below of the objects you believe are under the plate and how you believe they are arranged. Label all of the objects.

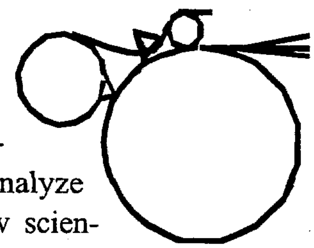


3. Now check with your partner about the items under the plate. How successful were you at predicting what was under the plate?

4. What are some ways in which you could you improve your predictions?

5. What skills and techniques used here are also used by Fermilab scientists as they study new particles?

Investigation 16: Tracking What Happened in an Unseen Event



Purpose:
Particle tracks give physicists indirect evidence about the particles involved in high-energy collisions. In this investigation, students will analyze and identify tracks made by colliding objects. Students will model how scientists use older bubble chamber photographs and current electronically recorded track data to identify particles inside the atom.

Objectives:
Students will create a "Master Sheet" of tracks as a key or control to identify unknown tracks.
Students will analyze and identify tracks made by moving objects from an unseen collision.

Materials:
Each group should get the following:
1 Master Sheet (one copy provided in guidebook)
1 ramp
1 ramp block
1 sheet of unlined paper (school supply)
1 sheet of carbon paper
4 metal balls - sizes from extra large to small (Use all metal balls in the kit except the BB-sized ones.)
1 set of bubble chamber photographs (in teacher assistance package)
Student Investigation Sheets - "Tracking What Happens in an Unseen Event"

Procedure:
1. Demonstrate how the ramp block set-up can be used to form an 8-cm "high ramp" or a 4-cm "low ramp."
2. Have students place the "Master Sheet" that has been provided, on a smooth, level, hard surface, and then place a sheet of carbon paper face down on top of the "Master Sheet" so that the labels on the long side are visible. Taping the sheets to the desktop will help secure them.
3. Next, have students set up the "low-ramp." Tell them to make sure that the bottom end of their ramps (rulers) are sitting on the carbon paper so that they will record the first mark the ball bearing makes on the data sheet.
4. Have them roll each of the four sizes of balls down the ramp and across the carbon paper at the appropriately marked spots, then move the ramp to the 8-cm "high ramp" height and finish the "Master Sheet."
5. Before they move on encourage students to identify at least three characteristics of the tracks that vary. For instance, are the high-ramp, extra-large-ball tracks the same size as the low-ramp, extra-large-ball tracks? How are they different? What about the high-ramp, extra-large-ball tracks and the high-ramp, small-ball tracks? Encourage students to differentiate tracks in as many ways as they can.

Note: You may want to experiment with a wide variety of carbon papers to determine which is most effective. (It has been the developers' experience that cheap, low-quality carbon paper works best.) Also, to ensure good tracks, the surface on which the balls roll must be smooth and hard.

Master Sheet Name____________

Low Ramp				High Ramp			
XLg	Lg	Med	Sm	XLg	Lg	Med	Sm

6. When students have completed their "Master Sheets" they will design and test a real collision by setting up balls on a blank sheet of paper with carbon paper over it and rolling another ball down either the high or low ramp to collide with them. Have them sketch their setup on a separate piece of paper, labeling the ball size and giving the ramp height and the size of the ball they launched.

   Note: Encourage them to try their setup and collision without the carbon paper a few times so that they know it will do what they want it to before they put the carbon paper down.

7. Each group will turn in their real collision sheet (unlabeled). Give each group's unlabeled sheet to another group to analyze. Keep the sketched copy to check the analyzing group's results.

   Note: You may want to create one collision prior to the start of this activity so that the first group to turn in their real collision sheet has a new one to analyze.

8. Upon completion of this investigation discuss the bubble chamber photograph as well as the electronic detector image provided in the kit with the class. Ask the students to explain how the trails in these pictures are different and how they might be used to identify particles.

   Note: Two features distinguish the tracks made by the metal balls: the darkness or intensity of the carbon mark as an indication of the ball's weight (or mass) and the spacing of the dashed carbon marks as an indication of the ball's speed.

   By contrast, bubble chamber particle tracks have three distinguishing features: length, curvature, and intensity. Length usually indicates the distance over which the particle traveled before decaying into some other kind of particle or being absorbed by a nearby atom. Particle decay can be identified by the new track of one of the decay-product particles.

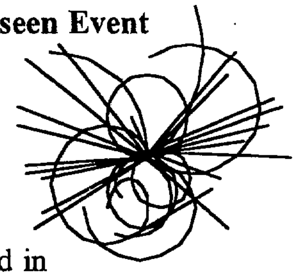
   Curvature of a particle trail is an indication of particle speed and mass (or weight) and is caused by the charged particle moving through a magnetic field. The field is caused by large electromagnet coils around the chamber. The particle's curved path is much like the *curving of protons around the circle of Fermilab's accelerator. The curvature is not caused by gravity nor by the commonly experienced attraction of metal objects to a magnet.*

Intensity of the tracks is a result of the combination of charge and speed. Therefore, intensity cannot be used without other evidence as a certain indicator of particle properties.

Finally, only charged particles (electrons, protons, etc., not neutrons, photons, etc.) make tracks in bubble chambers.

The main similarity between this tracking investigation and the bubble chamber is that both use tracks to draw conclusions about the mass and speed of objects in unseen collisions.

Student Sheet Investigation 16: Tracking What Happened in an Unseen Event



Name______________________________
Date______________________________

Purpose:

Particle tracks give physicists indirect evidence about the particles involved in high-energy collisions. In this investigation, you will analyze and identify tracks made by colliding objects. You will model how scientists use older bubble chamber photographs and current electronically recorded track data to identify particles inside the atom.

Procedure:

1. Place the "Master Sheet" on a smooth, level, hard surface. Place a sheet of carbon paper face down on top of the "Master Sheet" so that the labels on the long side are visible. Use tape to secure the sheets to the desktop.
2. Set up the ramp block and ramp as demonstrated by your teacher. Be sure that the front end of the ramp (ruler) is sitting on the carbon paper so that you will be sure to record the first mark the ball bearing makes on the data sheet.
3. Place the ramp at the 4-cm ("low ramp") height.
4. When all four balls have been released from the low ramp, repeat step 3 for the 8-cm "high ramp."
5. Your "Master Sheet" should have eight clear tracks on it. Keep this sheet to help you analyze a collision produced by another group later in this investigation.
6. Identify at least three characteristics of the track marks that vary. For instance, are the high-ramp, extra-large-ball tracks the same size as the low-ramp, extra-large-ball tracks? How are they different? What about the high-ramp, extra-large-ball tracks and the high-ramp, small-ball tracks?
7. Next, lay down a sheet of unlined paper. Place a combination of ball bearings on the blank paper wherever you want them. These ball bearings represent your target. Decide if you want to use the high ramp or the low ramp to create a collision with an incoming probe. Practice the collision a couple of times to be sure it is going to do what you want it to.
8. Now begin your collision again but cover the blank paper with carbon paper. Be careful as you set the collision up that you do not inadvertently create extra, confusing dots and marks on the collision sheet. Run the collision.
9. After the collision, sketch what happened on a separate piece of paper. Draw the ball bearings and their movement. Be sure to label which ball made each track and what height ramp was used.
10. Now, write the name of your group on both your real (unlabeled) collision sheet and your (labeled) answer key and turn them in to your teacher.
11. Your teacher will give you a real collision sheet produced by another group in your class. Analyze the tracks on this paper by comparing it with your "Master Sheet."
12. Identify the tracks on the other group's collision sheet with the size of the metal ball that produced them. Also identify the ramp height used for releasing the ball.

13. To check the results of your analysis, recreate this experiment with another sheet of paper and carbon. See if you can produce similar results.
14. When sure of your findings, write your group's name on the collision sheet you analyzed. Turn it in with your answers to the analysis questions.

Conclusions:

Answer the following questions.

1. From what ramp height did the other group release their ball probe?

2. What were the characteristics of the tracks that helped you determine the ramp's height?

3. What size metal ball(s) produced the tracks you analyzed?

4. What were the characteristics you used to make your decision in Question 3?

5. How did your "Master Sheet" help you reach your conclusions in this experiment?

6. How is this investigation different from Investigation 15? How is this investigation similar to what scientists do at Fermilab?

Low Ramp | High Ramp

X Lg | Lg | Med | Sm || X Lg | Lg | Med | Sn

Section 4: IDEAS

Introduction and Purpose:

Particle physicists use many different mathematical models and conceptual schemes to develop theories about the unseen world. Fermilab scientists make use of symmetry, classification, scaling, and ideas about relative size in their search for understanding. Each of these strategies can be used in many different ways and in many different situations.

These strategies or tools allow the physicist to organize and systemize efforts to discover some of nature's most cleverly hidden truths. An awareness of how these tools assist people every day gives us a peek into the life of a physicist at work.

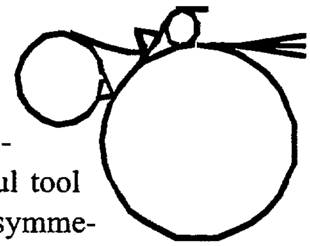
In this section students will explore how many different ideas can help in solving problems and creating new conceptual frameworks.

Objectives:

By the end of this unit, students will:

1. Use a variety of strategies to solve problems or visualize concepts. (These may include classification, symmetry, and modeling.)
2. Be able to describe ways in which Fermilab scientists:
    - use these strategies to solve problems or visualize concepts.
    - use these strategies to create and continually develop an understanding of nature's inner workings called the Standard Model.

Investigation 17: The Symmetry Scavenger Hunt



Purpose:

Symmetry is a very common tool particle physicists use to solve problems and discover new particles. The reason symmetry is such a powerful tool is that nature often has symmetric properties. Students will learn what symmetry is and how to use it to solve problems in which little evidence appears to exist.

Objectives:

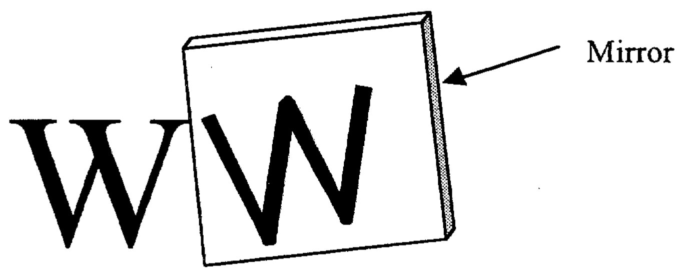
1. Students will become familiar with bilateral symmetry (also known as mirror symmetry).
2. Students will search for symmetry in the alphabet.
3. Students will identify symmetry in objects around them.
4. Students will explain how symmetry is important in particle physics.

Materials:

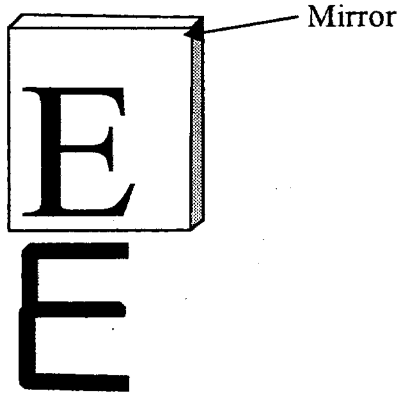
Paper and pencils
Small mirrors for each student

Procedure:

1. Explain what symmetry is to the students by pointing out that people are generally symmetric left and right. That is, the left side of our bodies generally looks like the right side. Take the time to note interesting differences in people as well. (Handedness is an excellent example of a break in the left-right symmetry in people.)
2. Explain that our alphabet is made of many letters that are also symmetric. The letter W for example is left-right symmetric. This means that if you look at a W in a mirror that is placed next to the letter it still looks like a W!



3. Point out that W is not symmetric in a mirror placed above it, so it is not up-down symmetric. The letter E, however, is up-down symmetric, even though it is not left-right symmetric.

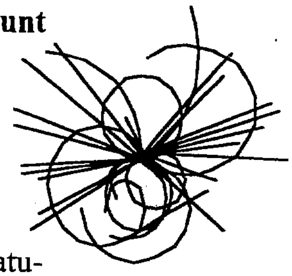


4. Ask the students to write the entire alphabet on a piece of paper and use the mirror vertically (as it is with W in the illustration above). Their goal is to list the left-right symmetric letters.

   Note: If desired, use a computer to produce neat, clean letters for the students. Be certain to choose a font that gives simple, clear letters. Arial is a good font for this.
5. Have them repeat the procedure with the mirror held horizontally (as it is with E in the illustration above). Ask them to list the up-down symmetric letters. Ask them if there are any letters that exhibit both left-right and up-down symmetry.
6. Now that students have had some exposure to the concept of symmetry, ask them to go on a symmetry scavenger hunt in the room. Have the students make a list of objects they find that exhibit left-right or up-down symmetry.
7. Discuss how the idea of symmetry may be important to an paleontologist trying to determine what an entire dinosaur looked like based on only a small number of bones.
8. Ask the students to discuss how a scientist at Fermilab might use symmetry to discover new unseen particles.

   Note: You may wish to point out that often certain particles are not found immediately, but through the use of symmetry, scientists believe that the particle will eventually be found. An excellent example is the most recently discovered quark, the top quark. It was presumed to exist long before it was found because the bottom quark, the other member of its "family," had been discovered in 1977. The missing member was called "top" for many years before it was actually seen for the first time at Fermilab.

Student Sheet Investigation 17: The Symmetry Scavenger Hunt



Name______________________________
Date______________________________

Purpose:
One of the most common ways physicists try to discover secrets of the natural world is to predict what an unseen particle might look like based on another particle that is well known. One process that helps the scientist is recognizing symmetry. You will model how scientists look for symmetry in the natural world by first discovering it in the alphabet and then looking for it in your classroom.

Procedure:

1. Print all of the capital letters of the alphabet. Make the letters large and as neat as you can. Leave space between the letters as well.
2. Set up a mirror to either the left or the right of each letter as your teacher illustrates. Some will appear backwards in the mirror, like E and Ǝ. Others will appear the same in both the mirror image and the paper image like A and A. Make a list of all letters that are the same both on paper and in the mirror in the space below. These are left-right symmetric letters.

3. Now check the alphabet again, holding the mirror above each letter. Notice this time that the letter A appears like ∀ in the mirror. It is symmetric left-right but not up-down! E however is up-down symmetric. Make a new list of the letters that are the same both on paper and in the mirror in the space below. These are up-down symmetric letters.

4. Compare your lists to those of other students in the room. Do you agree? Did you miss any letters?

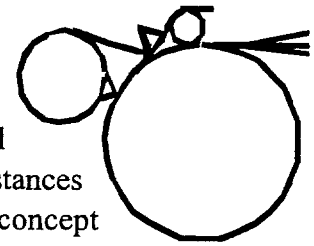
5. The symmetry you have discovered helps us to group letters in ways we had not before. In a similar way, scientists look for properties in nature which show some symmetry. Look around the classroom and find objects that have symmetry. Make a list of them here:

6. Compare your list with someone else's. Do you agree on all symmetries? What do you have that he or she doesn't? What is on your partner's list, but not yours? Why?

7. Can you think of any ways that symmetry might help a scientist solve a mystery? Describe a situation where symmetry might be used to solve a scientific mystery. Write a short explanation below.

8. How might particle physicists at Fermilab use symmetry to learn more about particles?

Investigation 18: *Cosmic Voyage* Film



Purpose:

Cosmic Voyage is an inspirational and educational journey. Students will "travel" from the depths of subatomic structure across the immense distances of our universe. Through the movie they will explore the mathematical concept of powers of ten and how it exponentially helps us understand the distances that exist between particles that make up the world around us.

Objectives:

Students will develop an appreciation of relative size and orders of magnitude (powers of ten).
Students will be able to compare the macrocosm of outer space to the microcosm of inner space.

Materials:

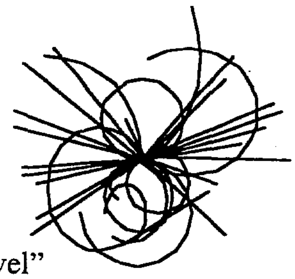
Cosmic Voyage film
Student Investigation Sheet: *Cosmic Voyage* Film

> *Note: The movie can be viewed as an introduction to the concept of powers of ten or as a means to apply student understanding from a classroom discussion to real life measurements in the study of matter.*
> *This investigation includes worksheet containing questions designed to focus student thinking, as well as a teacher answer key. Reading over these questions with students prior to viewing the video will enhance their understanding. Students understanding of just how much of matter is composed of empty space should definitely be part of your lesson planning for the unit.*
> *Show students the movie Cosmic Voyage in order to develop an appreciation (don't expect complete understanding) of relative size and orders of magnitude (powers of ten). The cosmic scale banner found in the teacher assistance package of the kit can be displayed and the decimal point moved in order to review steps in Cosmic Voyage. We have included a sample worksheet to be used in conjunction with this movie. You may wish to show the film more than once to increase your students' appreciation and understanding of the concept.*

Procedure:

1. Hand out the student investigation sheet.
2. Read through the questions in order to prepare the students for what they are going to see.
3. Display the cosmic scale banner from the teacher assistance package. Briefly "walk" through the powers represented on the banner.
4. Show the film *Cosmic Voyage.*
5. Determine ahead of time how students will be accountable for the video content. Ideas might be to have them taking notes during the presentation, individually after the presentation, or in small groups after the presentation?
6. Follow up the presentation with discussion.

Student Sheet Investigation 18: *Cosmic Voyage*



Name____________________
Date_____________________

Purpose:
Cosmic Voyage is an inspirational and educational journey. You will "travel" from the depths of subatomic structure across the immense distances of our universe. Through the movie you will explore the mathematical concept of powers of ten and how it helps us understand the distances that exist between particles that make up the world around us.

Procedure:
1. Watch the video *Cosmic Voyage.*
2. After the video follow your teacher's instructions regarding how he/she wants you to report on the content. It may be individually on the worksheet, through class discussion, or through a small group effort on the worksheet.

Cosmic Voyage reflection and discussion worksheet
1. What object in the video is equal to the 100th power of ten?

2. What landmark can be seen at the 102nd power of ten?

3. What object is visible at the 107th power of ten?

4. What power of ten is equal to the farthest reaches of human travel into our solar system?

5. At what power of ten is our solar system visible?

6. How many powers of ten is one light year?

7. What is a light year?

8. How long would it take at present-day spacecraft speeds to reach our nearest star?

9. At what power of ten makes the Milky Way galaxy visible?

10. What do we currently believe exists 15,000,000,000 light years from Venice?

11. What evidence did you find in this video that would support the idea that the universe is expanding?

12. What objects of measurement do we use in our everyday lives to determine whether something is large or small?

13. Under what circumstances might you use a different scale of large and small?

14. Why are Fermilab scientists trying to duplicate the conditions that existed at the start of the universe? How are they doing this?

15. Some scientists might say that the farther we look into space, the farther back in time we can see. What does this mean?

16. Compare the distribution of matter in outer space with the matter in atoms.

17. If an atom were as large as an Omnimax theater, how large would the nucleus be?

18. Do you believe that there is life present on other planets or in other galaxies? Why or why not?

19. What was the most difficult idea in part of this video for you to understand? Explain why.